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INVESTIGATION OF VELOCITY FIELD BEHIND LOW-FLYING WING WITH FUS--ETC(U)
MAY 77 M K BOCHIN, L G TSVETKOV

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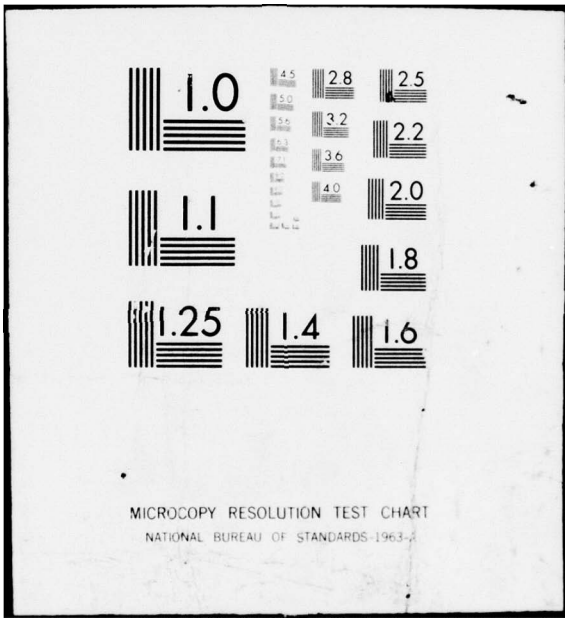
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FOREIGN TECHNOLOGY DIVISION

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by

M. K. Bochin, L. G. Tsvetkov

EDITED TRANSLATION

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Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
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М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ë in Russian, transliterate as yë or ë. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

GREEK ALPHABET

Alpha	A	α	*α*	Nu	N	ν	
Beta	B	β		Xi	Ξ	ξ	
Gamma	Γ	γ		Omicron	O	o	
Delta	Δ	δ		Pi	Π	π	
Epsilon	E	ε	*ϵ*	Rho	P	ρ	*ϱ*
Zeta	Z	ζ		Sigma	Σ	σ	*ς*
Eta	H	η		Tau	T	τ	
Theta	Θ	θ	*ϑ*	Upsilon	T	υ	
Iota	I	ι		Phi	Φ	φ	ϕ
Kappa	K	*κ*	κ *ϰ*	Chi	X	χ	
Lambda	Λ	λ		Psi	Ψ	ψ	
Mu	M	μ		Omega	Ω	ω	

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	$\sin^{-1}$
arc cos	$\cos^{-1}$
arc tg	$\tan^{-1}$
arc ctg	$\cot^{-1}$
arc sec	$\sec^{-1}$
arc cosec	$\csc^{-1}$
arc sh	$\sinh^{-1}$
arc ch	$\cosh^{-1}$
arc th	$\tanh^{-1}$
arc cth	$\coth^{-1}$
arc sch	sech^{-1}
arc csch	csch^{-1}
rot	curl
lg	log

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INVESTIGATION OF VELOCITY FIELD BEHIND LOW-FLYING WING WITH FUSELAGE

(Presented at Scientific and Technical Conference of Lenin Ship Building Institute (LKI), October 1969)

M. K. Bochin, Dept. of Hydromechanics; L. G. Tsvetkov, Dept. of Applied and Computer Mathematics

In this article we propose a method of investigating the velocity field behind a low-flying wing with fuselage. The value of the velocity field is necessary in calculating the aerodynamic characteristics of the tail assembly of aircraft which use the screen effect.

Numerical Calculation Method of Velocity Field

We investigate the uniform movement of a wing of finite span with a fuselage above a solid screen. The sheet of solid vortices which is formed twist, according to [1], into two vortex tip filaments, which lie upstream from the wing. The intensity and arrangement of the vortices are determined in the main velocity field behind the wing. Therefore, in our study we will ignore the stream caused by the attached wing vortex. Coordinate system Ox'y'z', attached to the wing (Fig. 1), is selected such that the attached vortex of the supporting wing lies within plane y'oz'; the ox' axis lies downstream from the fuselage; the oy' axis vertically above it. The fuselage is assumed to have the shape of a circular finite cylinder with a zero angle of attack. Our symbols are: u_0 - velocity of undisturbed oncoming flow parallel to ox' axis and plane of screen; Γ_+ - intensity of vortex tip filaments; ℓ - their distance from diametrical plane; e - elevation of free vortices above fuselage axis; h - distance of fuselage axis from screen; R - radius of cylindrical fuselage. Work [3] should be used as a guide in selecting the arrangement of the free vortex filaments.

In order to satisfy the condition of nonleakage on the fuselage from vortices 1 and 2 (Fig. 1) in the case of a wing and fuselage moving in an infinite fluid, according to [2] we place vortices 3 and 4 at the points of inversion inside the fuselage. In order to satisfy the boundary condition of nonpenetration in the case of a system moving near a solid screen, we map on it in mirror image relative to the plane of the screen the preceding vortex system, thus obtaining a hypothetical vortex system (vortices 5-8). In order to eliminate the violated condition of nonpenetration on the fuselage while preserving it on the screen, we use the method of successive inversion of vortices, in which each vortex of the hypothetical system (vortex A_0, Fig. 2) is mapped in relation to the surface of the fuselage, placing at the point of inversion vortex B_1, which is mapped relative to the screen - vortex A_1. Then, we perform a second approximation - vortex A_1 is mapped on B_2 and B_2 - on A_2, etc. As a result of this chains of vortices are formed inside the main and hypothetical fuselages, and in the presence of vortex A^*_0, which is symmetrical relative the diametric plane of vortex A_0, the same chains are formed, although this time symmetrical in relation to Ш with circulation of the opposite sign. After the γ-order of approximation the "residual leakage" of the fuselage is the result of vortices A_γ and A^*_γ, which, as the approximation order increases, move closer together, reducing the velocities induced by them and thus assuring necessary accuracy in satisfying the boundary condition on the fuselage. The complete

vortex system corresponding to the studied problem is shown in Fig. 1, where dashed lines represent the chains of vortices.

Let us determine vertical downwash $w = \frac{v_\xi}{u_0}$ at point M(x', y', z'), after introducing the dimensionless quantity

$$\Gamma = \frac{\Gamma_+}{u_0 \ell}; \quad \bar{R} = \frac{R}{\ell}; \quad \bar{e} = \frac{e}{\ell}; \quad \bar{h} = \frac{h}{\ell}; \quad x = \frac{x'}{\ell}; \quad \xi = \frac{\xi'}{\ell} \text{ etc.} \tag{1}$$

After applying the Biot-Savart formula to the elements of the vortex system of Fig. 1, we get:

$$w = \frac{\Gamma}{4\pi}\left[\sum_{n=1}^{8}(-1)^{n+1}\cdot\frac{z-\zeta_n}{r_n^2}\left(1+\frac{x}{\sqrt{x^2+r_n^2}}\right)+\sum_{\gamma=1}^{k}\sum_{\lambda=1}^{8}(-1)^{\lambda}\cdot\frac{z-\zeta_\lambda^\gamma}{(r_\lambda^\gamma)^2}\left(1+\frac{x}{\sqrt{x^2+(r_\lambda^\gamma)^2}}\right)\right], \tag{2}$$

where

$$r_n = \sqrt{(z-\zeta_n)^2+(y-\eta_n)^2}; \quad r_\lambda^\gamma = \sqrt{(z-\zeta_\lambda^\gamma)+(y-\eta_\lambda^\gamma)^2}; \tag{3}$$

η_n and ζ_n are the coordinates of vortices 1-8, where n is the number of the vortex according to Fig. 1.

The values of the coordinates have the form of

$$\left.\begin{aligned} &\zeta_1=\zeta_6=-\zeta_2=-\zeta_5=1; \quad \zeta_4=\zeta_7=-\zeta_3=-\zeta_8=\frac{\bar{R}^2}{1+\bar{e}^2}; \quad \eta_1=\eta_2=\bar{e} \\ &\eta_3=\eta_4=\bar{e}\frac{\bar{R}^2}{1+\bar{e}^2}; \quad \eta_5=\eta_6=-(2\bar{h}+\bar{e}); \quad \eta_7=\eta_8=-\left(2\bar{h}+\bar{e}\frac{\bar{R}^2}{1+\bar{e}^2}\right) \end{aligned}\right\}, \tag{4}$$

η_λ^γ and ζ_λ^γ are the coordinates of the vortices in the chain, where λ is the number of the chain (according tc Fig. 1); γ - the number of the vortex in the chain (or order of approximation).

The coordinates of the vortices in the chains in shifting from approximation γ to approximation $\gamma + 1$ when $\lambda = 6$ and $\lambda = 7$ are calculated according to the formulas:

$$\zeta_\lambda^{\gamma+1} = \frac{\bar{R}^2 \cdot \zeta_\lambda^\gamma}{(\zeta_\lambda^\gamma)^2 + (2\bar{h} + \eta_\lambda^\gamma)^2}; \qquad \eta_\lambda^{\gamma+1} = -\frac{\bar{R}^2(2\bar{h} + \eta_\lambda^\gamma)}{(\zeta_\lambda^\gamma)^2 + (2\bar{h} + \eta_\lambda^\gamma)^2}. \tag{5}$$

Then, the coordinates of the vortices in the chains for the given order of approximation (γ = const) are related to ζ_6^γ ; ζ_7^γ; η_6^γ and η_7^γ by relationships:

$$\left.\begin{aligned} &\eta_1^\gamma = \eta_2^\gamma = -(2\bar{h} + \eta_6^\gamma); \quad \eta_5^\gamma = \eta_6^\gamma; \quad \zeta_2^\gamma = \zeta_5^\gamma = -\zeta_1^\gamma = -\zeta_6^\gamma; \\ &\eta_4^\gamma = \eta_3^\gamma = -(2\bar{h} + \eta_7^\gamma); \quad \eta_8^\gamma = \eta_7^\gamma; \quad \zeta_3^\gamma = \zeta_8^\gamma = -\zeta_4^\gamma = -\zeta_7^\gamma \end{aligned}\right\}. \tag{6}$$

The coordinates of the first vortices in the chains ($\gamma = 1$) when $\lambda = 6$ and $\lambda = 7$ are determined by formulas (5) through coordinates with corresponding indices $n = 6$ and $n = 7$, which are calculated according to formula (4).

By using the Bernoulli equation and applying the Biot-Savart formula to the elements of the vortex system of Fig. 1, we get a formula for calculating the distribution of the pressure coefficient over the surface of a cylindrical fuselage:

$$\bar{p} = -\frac{\Gamma^2}{16\pi^2}\left[\sum_{n=1}^{k}(1)^{n+1}\cdot\frac{\bar{R}-\zeta_n\cos\theta-\eta_n\sin\theta}{\rho_n^2}\left(1+\frac{x}{\sqrt{x^2-\rho_n^2}}\right)+\sum_{\gamma=1}^{N}\sum_{\lambda=1}^{k}(-1)^{\lambda}\cdot\frac{\bar{R}-\zeta_\lambda^\gamma\cos\theta-\eta_\lambda^\gamma\sin\theta}{(\rho_\lambda^\gamma)^2}\left(1+\frac{x}{\sqrt{x^2+(\rho_\lambda^\gamma)^2}}\right)\right]^2, \quad (7)$$

where

$$\rho_n=\sqrt{(\bar{R}\cos\theta-\zeta_n)^2+(\bar{R}\sin\theta-\eta_n)^2}\,; \qquad \rho_\lambda^\gamma=\sqrt{(\bar{R}\cos\theta-\zeta_\lambda^\gamma)+(\bar{R}\sin\theta-\eta_\lambda^\gamma)^2}\,; \quad (8)$$

θ - is the polar angle of the studied point on the fuselage surface, reckoned from the horizontal plane.

In calculating quantities $\bar{w}$ and $\bar{p}$ according to formulas (2) and (7) we should limit ourselves to approximation $\gamma = k$, where the increment in the sum with respect to γ becomes lower than the required accuracy of calculating quantities $\bar{w}$ or $\bar{p}$.

According to this method a calculation was performed for a section of infinite distance downstream for the distribution of the reduced coefficient of pressure $\frac{\bar{p}}{\Gamma^2}$ over the surface of the fuselage

(Fig. 3) and the reduced vertical downwash $\frac{w}{\Gamma}$ along the wing span (Fig. 4) for the following calculated parameters:

$\bar{R} = \frac{R}{\ell} = 0,20$; $\bar{h} = \frac{h}{\ell} = 0,25$; $\bar{e} = 0$.

Investigation of Velocity Field on EGDA Device

For a section of infinite distance along the stream the investigation of the velocity field behind a low-flying wing with a cylindrical fuselage can be done on a plane electrohydrodynamic analogy device [the EGDA], as shown in Fig. 5.

The symbols in Fig. 5: 1 - sheet of electroconductive paper, 2 - bus, 3 - electrode which simulates vortex, 4 - sheet of electroconductive paper which simulates plane undisturbed flow, 5 - direct current source, 6 - galvanometer, 7 - probe.

Simulation of the free vortex flowing off of the wing tip is done by an electrode (source of electrical field). Observance of the boundary conditions requires that the contour (of fuselage and screen) in this analogy be made from a conductor. The symmetry of the flow in relation to the diametric plane is assured by installing a bus in this plane. In this case the force lines of the electrical field will correspond to the equipotential lines in the stream of

fluid, the equipotential lines of the electrical field - to the flow lines in the fluid.

The posed problem for a section of infinite length was modeled on the EGDA. The following was obtained: the field of vertical downwashes over the span of the wing (compared with calculations on Fig. 4), field of vertical downwashes at location of tail assembly (Fig. 6), and pattern of flow lines (Fig. 7) for following parameters: $\bar{R} = 0{,}20$; $\bar{h} = 0{,}25$ and $\bar{e} = 0$.

CONCLUSIONS 1. The experiments performed on the electrohydrodynamic analogy device verified the proposed method for calculating the velocity field behind a low-flying wing with cylindrical fuselage both qualitatively and quantitatively.

2. The cylindrical fuselage substantially affects the velocity field near the fuselage, within a region of 2-2.5 times its radius, decreasing or increasing the vertical downwash depending on the location of the studied point.

3. When the system of wing and fuselage approach the screen, the rarefaction curve on the surface of the fuselage, which is caused by the vortex sheet flowing off of the wing, decreases on one hand,

while on the other there occurs a redistribution in this curve, as a result of which additional lifting force develops on the fuselage. This deduction must also qualitatively be verified by the pattern of flow lines obtained on the EGDA.

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Fig. 1.

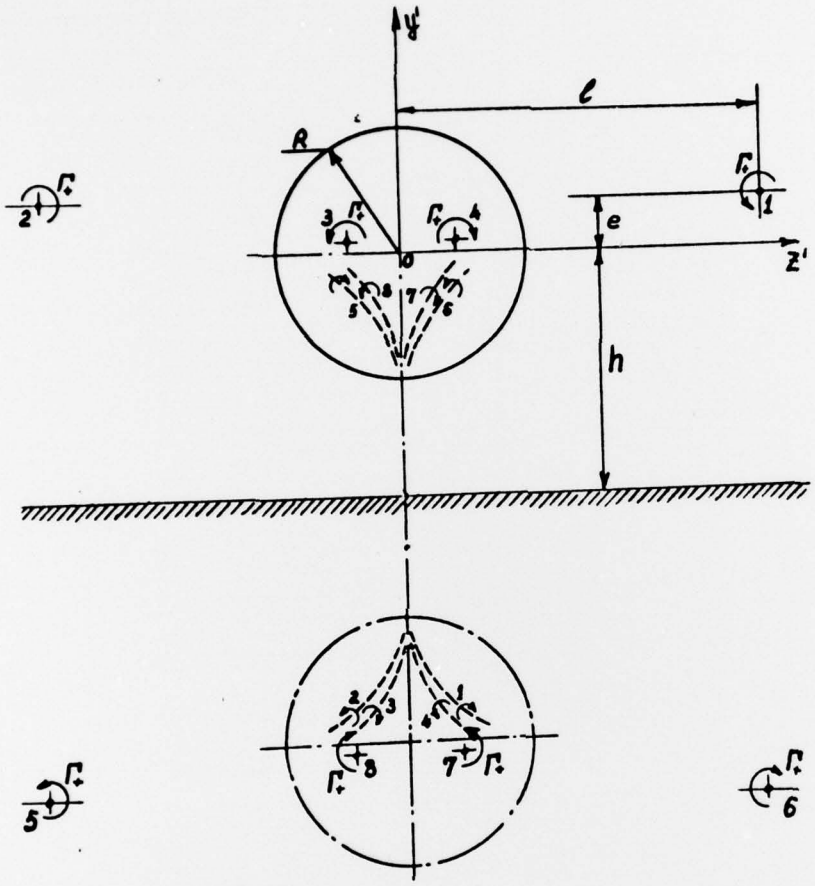


Fig. 2.

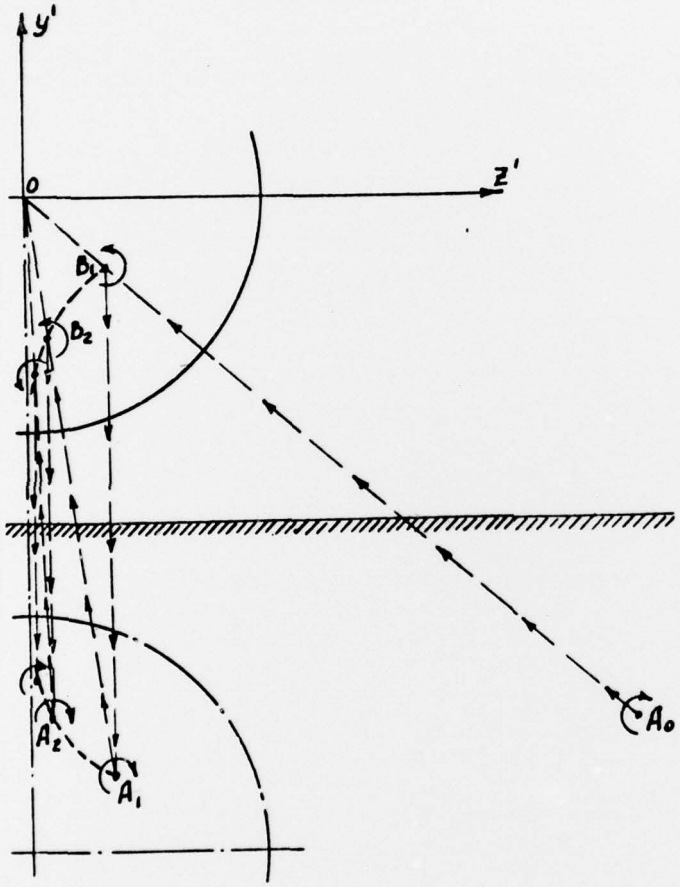
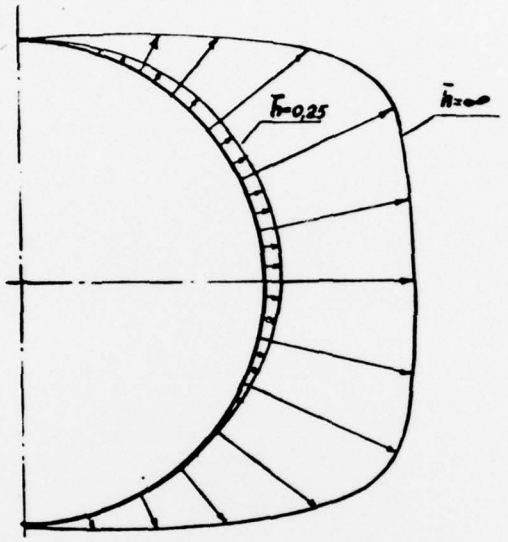


Fig. 3.



Key: (1) Scale $\bar{p}/g^2$.

Fig. 4.

Key: (1) with fuselage, (2) without fuselage, (3) experiment.

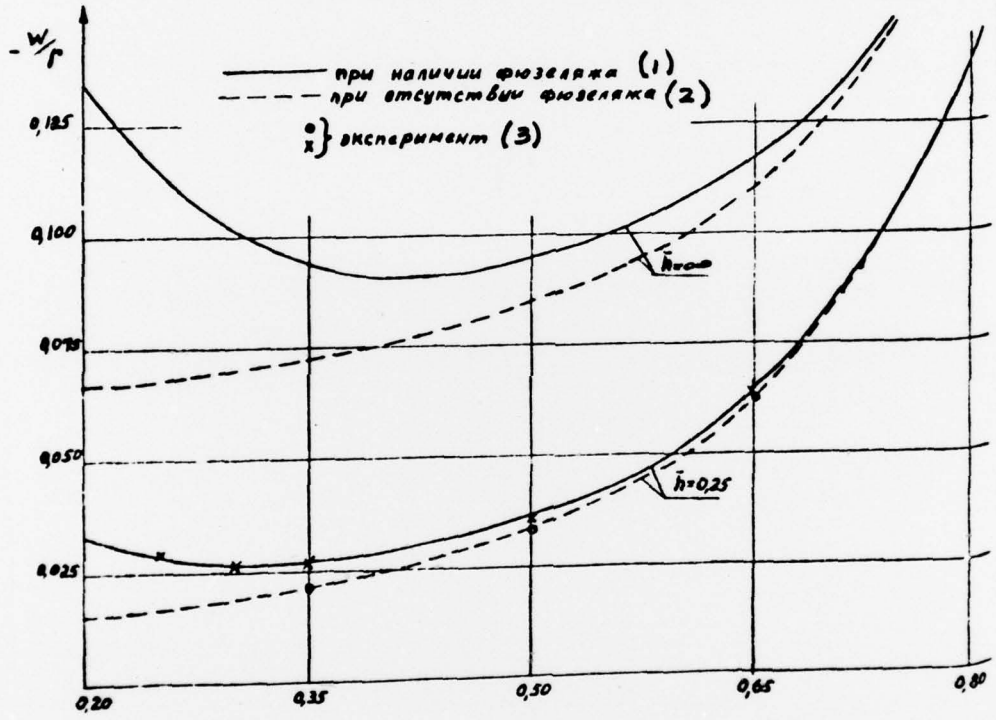
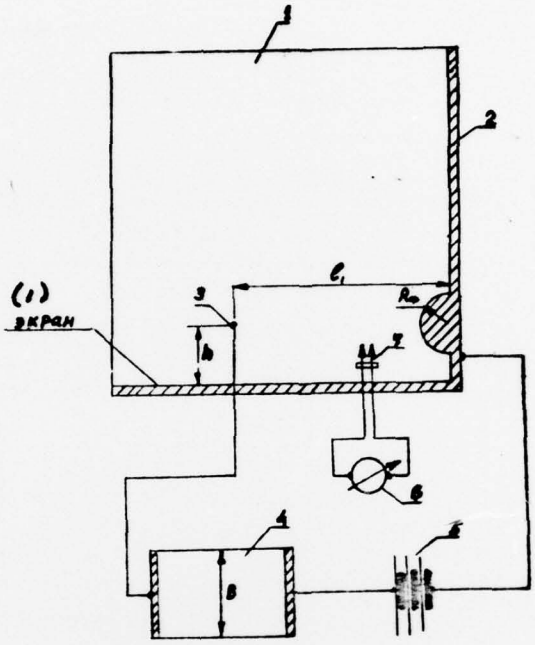


Fig. 5.



Key: (1) Screen.

Fig. 6.
Key: (1) without fuselage, (2) with fuselage.

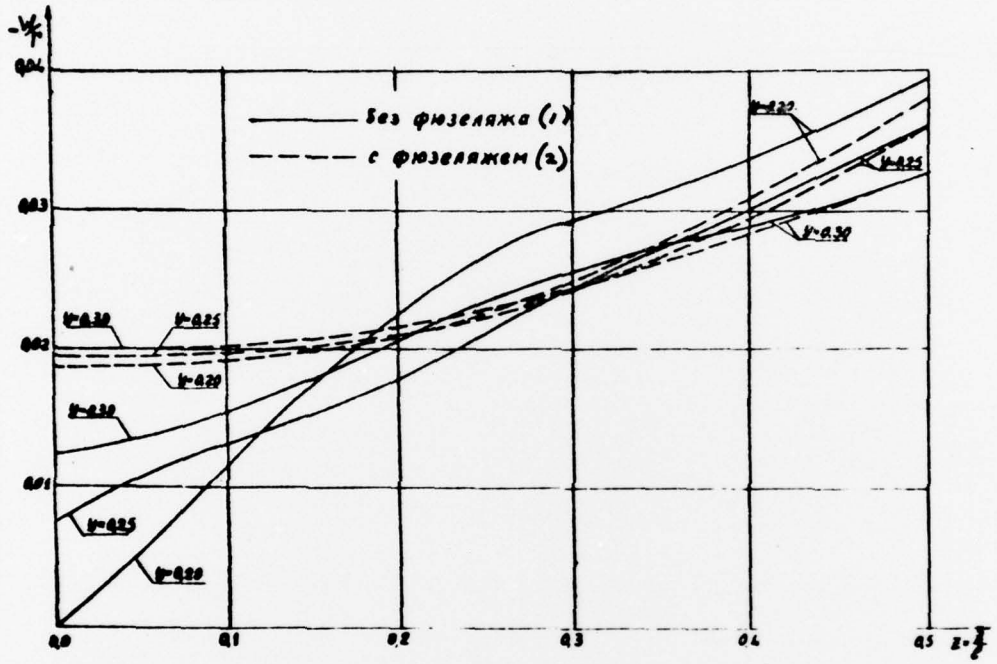
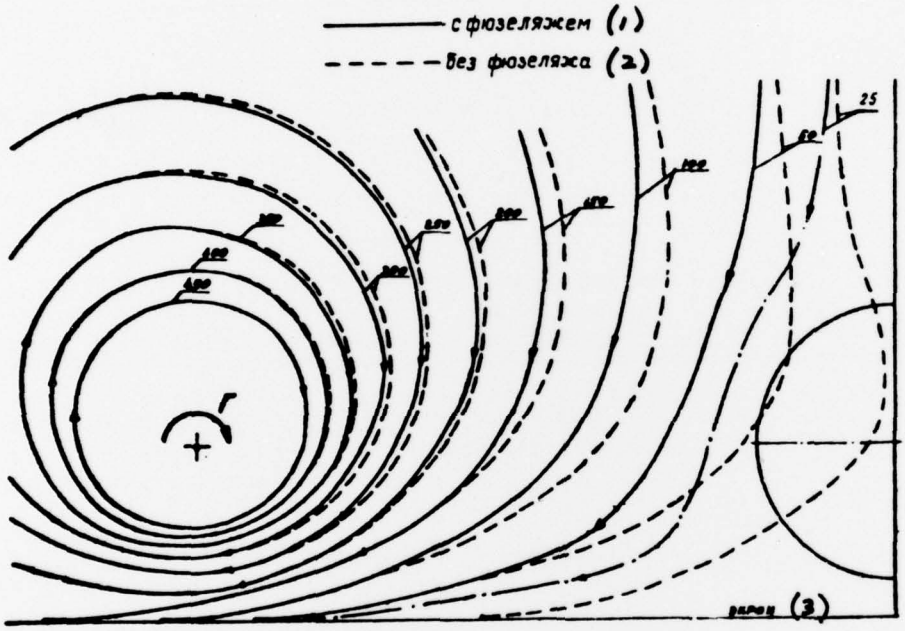


Fig. 7.

Key: (1) without fuselage, (2) with fuselage, (3) screen.



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